

Technical Memorandum 7c

Recommended Approach for a Food Web/Bioaccumulation Assessment of the Lower Fox River/Green Bay Ecosystem

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January, 2001

Acknowledgments

This technical memorandum was compiled by David Webb of the Wisconsin Department of Natural Resources. Assistance interpreting Lower Fox River/Green Bay fisheries biology information was provided by Terry Lychwick, George Boronow, and Brian Belonger of the Wisconsin Department of Natural Resources. Additional assistance preparing this report was provided by Timothy Thompson and Linda Mortensen of ThermoRetec, Inc., David Glaser and James Quadrini, Quantitative Environmental Analysis, LLC., and Mark Velleux, Wisconsin Department of Natural Resources.

Some of the information reviewed as part of this effort was prepared by Exponent, Inc. on behalf of the Fox River Group of Companies (FRG) under the terms of the January 31, 1997 Agreement with the State of Wisconsin. The contributions of Exponent staff are gratefully acknowledged. Funding for Exponent was provided by the FRG.

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1. Introduction

This technical memorandum is provided in partial fulfillment of the Memorandum of Agreement (“Agreement”) between the State of Wisconsin and seven paper companies (“Companies”), dated January 31, 1997.

Model evaluations will be undertaken according to the procedures discussed in the “Workplan to Evaluate the Fate and Transport Models for the Lower Fox River and Green Bay” (“Workplan”). This Workplan was developed by Limno-Tech, Inc. (LTI) on behalf of the Companies and the Wisconsin Department of Natural Resources (WDNR) and was conditionally approved by WDNR on September 26, 1997. This technical memorandum is a component of the Task 7 series of model evaluation work products and is entitled “Recommended Approach for a Food Web/Bioaccumulation Assessment of the Lower Fox River/Green Bay Ecosystem.”

The bioaccumulation of contaminants in the Lower Fox River/Green Bay ecosystem was explored as part of the 1989 Green Bay Mass Balance Study (GBMBS) (USEPA, 1989; USEPA, 1992 a,b). During the GBMBS, two different methods were used: 1) a biota to sediment accumulation factor (BSAF) approach, and 2) a bioenergetics-based food web approach. Ideally, one approach would be used for simulating contaminant bioaccumulation. The strengths and limitations of these two approaches were examined. Technical Memorandum 7a (Exponent, 1999a) evaluated the potential application of the BSAF approach. Technical Memorandum 7b (Exponent, 1999b) evaluated the potential application of the food web approach. The objective of this technical memorandum is to recommend a preferred approach for calculating fish tissue concentrations and specify the information needed to apply this approach to the Lower Fox River and Green Bay.

Based on the assessments presented in Technical Memoranda 7a and 7b, the bioenergetics-based food web approach was selected as the preferred approach for calculating fish tissue contaminant concentrations. To apply a food web approach to a site, it is necessary to specify information regarding food web structure and contaminant exposure. The report sections that follow review the information needed to apply the food web approach to the Lower Fox River/Green Bay site and include an identification of habitats, descriptions of the life histories and dietary preferences of relevant fish species, population dynamics, and fish migration patterns. This information was then used to specify the food web structure and define the exposure assumptions necessary to simulate contaminant bioaccumulation in the Lower Fox River and Green Bay.

It should be noted that the information presented in this report considers assessments of Lower Fox River/Green Bay food webs as described by the Green Bay Food Web model (Connolly et al. 1992; HydroQual, 1995), a review submitted by Exponent (1999c) on behalf of the Fox River Group, and the Draft Baseline Risk Assessment for the Lower Fox River (ThermoRetec, 1999). One specific goal of this work effort is to present a consistent methodology to simulate the bioaccumulation of contaminants in the food web of the Lower Fox River and Green Bay for use in model evaluation and State of Wisconsin-led Natural Resources Damage Assessment (NRDA) and Superfund (CERCLA) Remedial Investigation/Feasibility Study (RIFS) and Risk Assessment (RA) efforts.

2. General Information and Site Description

2.1 Area Definitions

The area of concern includes the Lower Fox River and all of Green Bay. The Lower Fox River is 39 miles long and extends from the outlet of Lake Winnebago, flowing north, to Green Bay. Green Bay begins at the mouth of the Lower Fox River, extends north for approximately 190 kilometers (km) (119 miles), and has an average width of 37 km (23 miles).

The Lower Fox River is a highly controlled river impounded by a series of 12 dams and 17 locks, which made it once navigable between Lake Winnebago and Green Bay. The river is still navigable to recreational boats, but the Rapids Croche lock is permanently closed to restrict sea lamprey migration. For the purposes of evaluating important fish species and modeling their potential uptake of PCBs, the river may be discussed in terms of four reaches as follows:

Little Lake Butte des Morts: the river from the outlet of Lake Winnebago to the city of Appleton, including Little Lake Butte des Morts (LLBdM);

Appleton to Little Rapids: the river from approximately Appleton to Wrightstown;

Little Rapids to DePere: the section of the river from Little Rapids to the DePere dam;

DePere to Green Bay (Green Bay Zone 1): the approximately 11 km (7 miles) of river downstream of the DePere to the mouth of Green Bay;

Green Bay is a narrow, elongated bay, approximately 190 km (119 miles) in length and an average of 37 km (23 miles) in width. Within the comprehensive Green Bay Mass Balance Study (USEPA, 1992a,b), the bay was further evaluated in four zones defined as follows:

- Zone 1: DePere Dam to Green Bay (the last seven miles of Lower Fox River),
- Zone 2: lower bay area from the Lower Fox River mouth to a line traversing the bay at Long Tail Point,
- Zone 3: middle bay area from Long Tail Point to Chambers Island, and
- Zone 4: upper bay area from Chambers Island to Lake Michigan, including the islands marking the entrance to Lake Michigan.

Zones 2,3, and 4 can be considered as "east" and "west" reaches based upon a line drawn from Chambers Island to the mouth of the Fox River, where those on the west side of the Bay are denoted as "A" and those on the east side of the Bay are denoted as "B." For the purposes of model evaluations in Zones 1 through 4, only Zone 3 will be independently evaluated as Zone 3A (the west side) and Zone 3B (the east side). This distinction is noted for Zone 3 because much of the area in Zone 3B is part of the Lower Fox River depositional zone (Lathrop et al., 1990) and, therefore, potentially quite different in terms of uptake from Zone 3A.

Biota samples obtained during the Green Bay Mass Balance Study (GBMBS) were collected from each of three broad zones. The boundaries of each biota collection zone were defined by

latitudinal lines as shown in the GBMBS (USEPA, 1992b). During the GBMBS, these biota collection zones were translated to the computational grid of the Green Bay toxics model (GBTOX) and used to define “exposure” zones for subsequent bioaccumulation simulations. The boundaries of each exposure zone were defined by the location of GBTOX model water column segments. The exposure zones define the areas over which biota exposure to chemicals (computed as temporally and spatially averaged water column and surface sediment PCB concentrations) is assumed to occur. The exposures are the “linkage” between the GBTOX water quality model and the GBFOOD bioaccumulation model.

2.2 Aquatic Ecosystems of the Lower Fox River and Green Bay

The aquatic ecosystem within the Lower Fox River and Green are those associated with wetland, riverine, and lacustrine habitats. These in turn support include a wide variety of insect, invertebrate, and fish species. Each of these influence the selection of the important food webs of each system, and are discussed in more detail below.

2.2.1 Habitats

Within the Lower Fox River and Green Bay there are three specific habitat types that are important to fish species: wetlands, riverine and the lacustrine systems found in Green Bay. These are discussed in more detail below.

2.2.1.1 Wetlands

Wetland habitat is probably the most critical habitat within the Lower Fox River and Green Bay area, providing an important habitat for all wildlife groups. For fish, the emergent/wet meadow wetlands provide foraging or spawning habitat for a variety of fish species including northern pike, bass, sunfish, yellow perch, carp, alewife, rainbow smelt, and shiners (Brazner, 1997). These wetlands/wetland complexes are typically present along the west shore and tributary mouths of Green Bay, as well as in the backwater covers of Little Lake Butte des Morts and the Lower Fox River (Exponent, 1998). Typical emergent vegetation in these wetlands include cattails, bulrush, arrowhead, assorted rushes, sedges and reeds (Exponent, 1998). The submergent and floating aquatic vegetation within these marshes primarily consists of water-milfoil, coontail, wild celery, pondweeds, and water lilies (Exponent, 1998).

In addition to wetlands, submerged aquatic vegetation also comprises an important component of the fish habitat. Exponent (1998) documented the presence and areal extent of submerged aquatic vegetation (SAV) within each portion of the Lower Fox River. SAV form a significant habitat complex within Little Lake Butte des Morts and within the Appleton to Little Rapids reach within the vicinity of the 1,000 Island conservancy, but are only a small part of the available habitat within the last two river reaches.

For Green Bay, wetlands along the east side are generally classified as palustrine (marsh or swamp) (USFWS, 1981). Palustrine wetlands generally lack flowing water and have water depths less than 1.8 meters (6 feet) deep. Exponent (1998) described the largest east shore wetlands (from the Lower Fox River to Little Sturgeon Bay) as emergent/wet meadow wetlands. Based on the information provided by Exponent (1998) and the USFWS (1981) descriptions, many of the wetlands along the east shore of Green Bay are emergent/wetland meadow complexes.

The west shore of Green Bay has significantly more wetlands. This includes all shoreline from the mouth of the Lower Fox River to the city of Escanaba, Michigan. From the mouth of the Lower Fox River to the city of Oconto, Exponent (1998) classified slightly more than 50 percent of the wetlands as emergent/wet meadow. The information provided by USFWS (1981) and Minc and Albert (1998) suggest that wetlands further north of the city of Oconto are similar, as palustrine wetlands are usually found with the lacustrine areas. Almost all of the west shore wetlands were primarily classified as lacustrine systems by the USFWS (1981). These wetlands are affected by littoral currents, storm driven wave action, wind action, and ice scour, the primary causes of shoreline sediment deposition and erosion (Minc and Albert, 1998). These lacustrine systems have developed in the shallows of the bay and many of them in Wisconsin water are associated with the Green Bay tributary spits or deltas. Only wetlands associated with river deltas are classified as riverine systems. These include select portions of the Atkinson Marsh (Duck Creek), Oconto Marsh (Oconto River), Peshtigo River Wetland, Cedar River Wetland Complex, and Ford River Wetland Complex.

2.2.1.2 Riverine Habitat

Riverine aquatic systems refer to the rivers and tributaries of the Great Lakes whose water quality, flow rate, and sediment loads are controlled in large part by their drainage basins. The Habitat Characterization Assessment (Exponent, 1998) divided the Lower Fox River into two parts, upstream and downstream of the DePere dam. The upstream portion is comprised of the Little Lake Butte des Morts, Appleton to Kaukauna, and Kaukauna to DePere reaches, while the downstream portion is comprised of the DePere to Green Bay reach.

2.2.1.3 Lacustrine Habitat

The lacustrine system of Green Bay has deeper water, allowing temperature stratifications (thermocline) to develop. The presence of a thermocline provides large water bodies the ability to host a wider diversity of species of fish and other aquatic organisms that may prefer a warmer or colder temperature environment. Fish species can be found within different areas and at various depths of lacustrine habitat based on the water depth, currents, and temperature.

Other unique aspects of lacustrine environments are related to water currents, sediment deposition and erosion, and the wetland complexes that develop therein. Unlike rivers, which basically have a unidirectional current (gravitational), lacustrine currents are more complex, variable, and weaker (Maitland and Morgan, 1997). Also, sediment erosion within Green Bay is largely confined to shore and nearshore areas, where wind, wave action, and ice scour are the primary causes for erosion and redeposition. Bottom sediments transported from the Lower Fox River and other tributaries into Green Bay are typically deposited nearby the source mouth. This is evidenced by the thick sediment deposits and shallow water depths at the southern end of the bay (Lower Fox River/Duck Creek mouths) and the spits, shoals, and shallows located near the mouths of the other significant tributaries along the west side of the bay. Lacustrine environments typically develop larger wetlands than riverine systems, especially in areas of extensive shallow water and low current velocities, as described above.

Lacustrine environments are generally categorized based on the biological conditions of the system and the three classifications are eutrophic, oligotrophic, and dystrophic. Lower Green Bay is eutrophic and the northern end is generally oligotrophic. Eutrophic lakes are nutrient rich,

usually shallow, turbid waters that may experience oxygen deficiencies under the ice or in deeper areas at certain times of the year (Maitland and Morgan, 1997). Oligotrophic lakes are typically deep, clear waters that are nutrient poor and rarely, if ever, have oxygen deficiencies (Maitland and Morgan, 1997). In addition, Green Bay is also mesotrophic in areas; the mesotrophic classification is an intermediate between eutrophic and oligotrophic conditions.

2.2.2 Phytoplankton and Invertebrates

Phytoplankton and invertebrates form the basis of the food chain in the Lower Fox River and Green Bay. Both pelagic and benthic aquatic invertebrate species form the primary prey in the food webs of the river and bay. Species of oligochaetes and chironomids (worms and midges) are typically most abundant and are found throughout the Lower Fox River and Green Bay. Amphipods, crayfish, snails, and mussels are also present in the river and bay. Zebra mussels, an exotic species, are present throughout Green Bay and in parts of the river.

2.2.2.1 Phytoplankton

The phytoplankton component of the Lower Fox River and Green Bay is outlined in the Green Bay/Fox River Mass Balance Study (U.S. EPA, 1989, U.S. EPA 1992 a,b).

2.2.2.2 Invertebrate Communities

The invertebrate fauna of the lower Fox River and Green Bay include species that are found within the water column and benthic species that are found in or upon the surface sediments. Feeding ecology studies conducted in the Great Lakes indicate that the prey species depend upon the fish species examined and the habitat examined. In wetland and riverine systems, benthic and epibenthic invertebrate species (amphipods, chironomids, and oligochaetes) tend to predominate, while in open water lacustrine systems zooplankton such as copepods and cladocera (Gannon, 1974) will predominate.

In the Lower Fox River and Green Bay environment, the benthic macroinvertebrates include adult and larval insects, mollusks, crustaceans, and worms. Given the predominance of fine-grained silt/clay sediments in the river, the predominant species are sediment dwelling and burrow directly into the substrate for most of their life cycle. The benthic macroinvertebrate community plays a vital role in ecosystem functions such as nutrient cycling and organic matter processing, and is an important food resource for the benthic and pelagic fish communities, as well as semi-aquatic organisms such as birds and mammals.

The benthic infauna of the Lower Fox River and Green Bay are dominated principally by chironomids and oligochaetes, with round worms, flat worms, scuds, caddisflies, leeches, and sowbugs completing the inventory (Call et al., 1991; Integrated Papers Services [IPS], 1993a, 1993b, 1994, and 1995; and WDNR, 1996). These studies showed that the benthic macroinvertebrate communities from upstream reference sites and locations in Green Bay far from the mouth of the river were higher in taxa richness than the Lower Fox River sites. Mayflies (*Caenis* sp.; *Hexagenia* sp.), which are common in other Great Lake riverine systems, are not currently found in the Lower Fox River or lower Green Bay (WDNR, 1996; Call, et al., 1991). The invasion of zebra mussels will likely alter the current benthic communities in the future due to the ability of this exotic species to out-compete the local benthic species for food and habitat (IPS, 1995).

The two most important benthic invertebrates from a prey standpoint are the chironomids and oligochaetes. Chironomids, or midge larvae, live directly within the soft sediments, and are known to be an important resource for maintaining fish populations (Pennak, 1978). There are many species of chironomids with various feeding behaviors, but in general they derive nutrition by ingesting sediment detrital materials. (Pennak, 1978). Oligochaetes, which are aquatic segmented worms, are also detritivores, ingesting whole sediment and digesting organic material as it passes through the alimentary canal (Pennak, 1978).

Two particularly important organisms in the Green Bay food web are *Mysis relicta* and *Diporeia hoyi*. While the consumption of phytoplankton by copepods and cladocera is well documented (Pennak, 1978), the relative importance of sediment and water column particulates as food sources to the major benthic invertebrate species is less clear. The feeding strategies of these benthic invertebrates are discussed below.

M. relicta can be an important source of nutrition for forage fish (Grossnickle, 1982). In general, *M. relicta* feeds within the water column and can exert considerable influence over planktonic assemblages (Grossnickle, 1982; Bowers and Grossnickle, 1978; Bowers and Vanderploeg, 1982). This invertebrate exhibits diurnal vertical migrations in the water column in response to the availability of food (Grossnickle, 1979), during which time it becomes available as food for forage fish. *M. relicta* can also feed upon sediment bed material, although Klump *et al.* (1991) considered sediments to be a secondary source of nutrition for this species. *M. relicta* is generally found in greater abundance towards the western shore of Green Bay and to a lesser extent on the eastern shore. *M. relicta* is generally not present in the southern portion of Green Bay (Raids, 2000).

D. hoyi is the dominant amphipod in the off-shore waters of the Great Lakes (Landrum and Nalepa, 1998). The extent to which *D. hoyi* inhabit the waters of Green Bay is limited to the northern portions of Green Bay (Green Bay Zones 3 and 4). This amphipod is a benthic detritivore that consumes particulate material within the top 2 centimeters of the sediment bed, feeding primarily on bacteria-rich detritus and settled algae (Quigley, 1988). *D. hoyi* migrates into the water column, during which time it becomes available as food for forage fish. *D. hoyi* feeds selectively on particles that are rich in organic carbon, preferring freshly settled particles to aged sediment particulates (Dermott and Corning, 1988).

In contrast to most other amphipods, *D. hoyi* appears to eat more intensively during algal blooms than during other times of the year (Gauvin *et al.*, 1989; Dermott and Corning, 1988). For example, *D. hoyi* populations have been reported to consume a significant fraction of the spring diatom bloom in Lake Michigan (Fitzgerald and Gardner, 1993). Further, seasonal changes in growth rates and lipid levels suggest that *D. hoyi* rapidly assimilates newly settled detritus, when available, and is adapted to seasonally limited food (Gardner *et al.*, 1985; Gauvin *et al.*, 1989; Dermott and Corning, 1988). Finally, carbon, and PCB assimilation efficiencies are likely to be greater for freshly settled material than for aged sediment carbon (Landrum and Nalepa, 1998). Thus, due to a large component of freshly settled material in the diet, seasonal feeding on algal blooms, and high PCB assimilation efficiencies from freshly settled material *D. hoyi* most likely accumulates PCBs primarily from water column particulates rather than sediment detritus.

2.2.3 Fish

Through the mid-1970s the population levels of fish species, such as walleye and perch, were low within the Lower Fox River and southern Green Bay ecosystems. Contaminants along with low dissolve oxygen conditions brought about by uncontrolled and untreated wastewater dumped into the river were believed to be a contributing factor causing low population levels. Principal species found within the system were those that could tolerate these conditions, especially bullhead and carp.

With the institution of water quality controls in the mid-1970s, contaminants and D.O. conditions improved and the WDNR undertook a program to reintroduce walleye into the river and bay through a stocking program beginning in 1973. That program was wholly successful; self-sustaining populations of walleye now exist within the river and bay. In addition to walleye, a number of other species became reestablished in the Lower Fox River including white and yellow perch, alewife, shad, bass, blue gill, and other species.

The fishery habitat of Green Bay varies considerable based on the water characteristics and bay bathymetry. Green Bay Zones 2 and 4 are quite different in terms of their physical characteristics, which affects species distribution and trophic complexity. Green Bay Zone 2 is hypereutrophic (warm and highly productive), while Zone 4 is meso-oligotrophic (cooler and less productive). Related distinguishing characteristics of Zone 4 are that there are lower population densities of fish, less trophic complexity, clearer water, and less human development as compared to Zone 2 (Brazner and Beals, 1997; Sager and Richman, 1991).

Green Bay south of the Peshtigo Reef (west side) and Sturgeon Bay (east side) is generally a warm-water fishery, with eutrophic water conditions, significant plankton populations, and numerous fish species (Toneys, 1999; Belonger, 1999). This fishery is separated from the cold-water fishery to the north by the circular, counterclockwise water currents, one of which runs west from Sturgeon Bay on the east side toward the Peshtigo Reef on the west side. North of Peshtigo Reef and Sturgeon Bay, the fishery is a cold-water, meso-oligotrophic system with reduced plankton populations and fewer fish species (Schneeberger, 1999). The general observations of the Green Bay fisheries are described below. Fish with each of these fisheries tend to remain in one area or the other. Tagging studies of yellow perch and smallmouth bass indicate that these fish tend to stay within the area where they were caught (i.e., yellow perch in the warm, south bay waters do not typically migrate to the cold-water fishery of the north bay) (Toneys, 1999). Similarly, the Sturgeon Bay Canal is prone to seiche effects and water temperature changes of 5.5° to 11°C (10° to 20° F) in a single day. Therefore, fish within Green Bay may move into Lake Michigan and vice-versa, but this is not a significant migration route (Toneys, 1999).

South of the Sturgeon Bay-Peshtigo line, heavily pursued sport fish include walleye, yellow perch, northern pike, and spotted muskellunge (muskie). North of Sturgeon Bay-Peshtigo smallmouth bass, brown trout and salmonids are also pursued (Toneys, 1999; Belonger, 1999). The yellow perch and alewife are the predominant commercial species in the southern area, especially during the summer. During the winter, the lake whitefish become an important commercial species. The whitefish prefer cold waters and are fished in the northern bay year-round. However, when water temperatures decrease south of Sturgeon Bay-Peshtigo, these fish

migrate south in pursuit of food (Toneys, 1999; Belonger, 1999). A thermocline has been observed in this area, which tends to form and stay near a depth of 3 to 12 meters (10 to 40 feet), based on weather conditions. If a consistent northeast wind is experienced, this may push the thermocline down to depths of approximately 18 meters (60 feet) (Belonger, 1999).

In northern Green Bay, walleye, yellow perch, northern pike, splake, chinook salmon, smallmouth bass, and brown trout, are the main sport fish. In Michigan, the annual sport catch of walleye may range between 30,000 and 90,000 kg (66,100 and 198,400 pounds) while the yellow perch catch is on the order of 10,000 to 80,000 kg (22,050 to 176,400 pounds) (Schneeberger, 1999). Commercially, the lake whitefish and rainbow smelt are the main species pursued. The annual whitefish catch ranges from 1 million to 1.5 million kg (2.2 million to 3.3 million pounds) while the smelt catch is on the order of 50,000 to 200,000 kg (110,230 to 440,900 pounds) (Schneeberger, 1999).

The commercial fishery for lake whitefish has increased significantly over the last 20 years, and the catches are near an all-time high (Belonger 1999; Schneeberger, 1999). In the northern half of Green Bay, the walleye fishery has also increased in the number of fish caught for each hour of fishing and the total numbers of walleyes taken (Schneeberger, 1999).

In addition to these observations, Brazner and Magnuson (1994) found that more fish preferred the nearshore wetland habitats to beaches, which have fewer plants and stronger wave action. In 1997, Brazner indicated that fish populations in the vicinity of undisturbed wetlands were greater than those in disturbed wetlands or beach areas. More forage species and the majority of the game fish captured, including yellow perch and bluegills, were taken in the vicinity of undisturbed wetlands. The highly productive (eutrophic) southern bay provided a better forage base for fishes than did the meso-oligotrophic northern end (Brazner, 1997). This is very important for young fish, which almost all forage on zooplankton at some point during maturation (Brazner, 1997).

The overall patterns of fish abundance, species distribution, and habitat use by fish in Green Bay have been recently well characterized by Brazner and colleagues at the University of Wisconsin (Brazner, 1997; Brazner and Beals, 1997; Brazner and Magnuson, 1994). Each of these papers summarized data collected from 24 stations extending the whole length of Green Bay: eight stations in Zone 2, eight stations in Zone 3, and eight stations in Zone 4. All of these stations were along the western side of Green Bay except for one station on the eastern side of Zone 2, Point Sable. The two habitats targeted for sampling were wetlands (12 stations) and sandy beaches (12 stations). Additionally, half of the stations for each of these two habitats were selected because they were developed, and the other half were selected because they were undeveloped.

These stations were sampled in the summer and fall of 1990 and 1991, and in the spring of 1991. Almost 42,000 fish, representing 54 species and 20 families, were caught and analyzed over these sampling periods. Most of these fish (86 percent) were immature (younger than 2 years old) likely because of the small mesh sampling gear used which favored selection of younger age classes of fish.

These data collected by Brazner and colleagues were analyzed to determine to what degree fish preferentially used different regions of the bay, habitats within those regions, and to what degree human development impacted habitat use. Statistical analyses including cluster analysis, ordination, and discriminant analysis, indicated that regional differences most strongly influenced fish assemblages, followed by habitat differences, and the least determining factor was development status.

Approximately half (49 percent) of all the fish collected came from Zone 2, most of them captured in undeveloped wetlands, and only 16 percent came from Zone 4. Not only was abundance greater in Zone 2, but also species richness. Of the regional characteristics measured, turbidity was determined to be the best predictor of fish abundance. Other important regional characteristics included water temperature, conductivity, and pH (Brazner and Beals, 1997).

Habitat differences adequately defined fish assemblages for Green Bay Zones 3 and 4, but they were not a good predictor for Zone 2 (Brazner and Beals, 1997). Macrophyte level was the habitat characteristic that best predicted fish assemblages. When macrophyte cover and richness is high, the same is generally true of fish richness and abundance (Brazner and Beals, 1997). An exception to this is where macrophyte cover is so dense that it has limited utility for fish.

Turbidity, in addition to being a primary regional characteristic, is a key limiting factor to macrophyte growth and, therefore, habitat differences (Brazner and Beals, 1997). Areas that are highly turbid, such as Green Bay Zone 2, have less developed macrophytes, whereas Zone 4, which has clear waters, has well developed macrophytes. Overall, these differences have resulted in lower biomass, and vegetation-dependent fish in Zone 4 (centrarchids, northern pike, golden shiners) and higher biomass, more turbidity-tolerant fish communities in Zone 2 (gizzard shad, white bass, common carp) (Brazner and Magnuson, 1994). Turbidity in Zone 2 is assumed to be equally influenced by biotic (phytoplankton production) and abiotic (erosion, runoff, and resuspension) factors (Brazner and Beals, 1997). It has been estimated that 70 percent of the water in Zone 2 (Long Tail Point to Point Sable) is composed of Lower Fox River water (Brazner and Beals, 1997).

In terms of trends in individual species, spottail shiners were the most abundant fish, with over 122,000 individuals caught in the spring of 1991 (Brazner, 1997). Catch of this species was not dependent on habitat type, but was dependent on region; 93 percent of the catch was obtained from Zone 2. Excluding these spottail data, spottail shiners were still one of the top five most abundant species caught; the remaining top five species were yellow perch, alewife, spotfin shiner, and bluntnose minnow. Yellow perch represented about 25 percent of the approximately 42,000 fish caught, and spottail shiner represented approximately 22 percent.

For 21 of the 54 fish species caught, either more than 80 percent of the individuals or at least a significant number of them were caught in one zone. These results demonstrate that regional differences were stronger determining factors of fish assemblage than habitat or development. Of these 21 zone-biased fish species, freshwater drum, white bass, and gizzard shad were caught almost exclusively in Zone 2, and golden shiners, pumpkinseeds and logperch were most often caught in Zone 4 (Brazner, 1997). The three species that were dominantly caught in Zone 3

(rainbow smelt, trout, perch, and banded killifish) were not the most abundant fish caught in this zone.

Specifically, for receptors selected for risk evaluation of the Lower Fox River and Green Bay, the following information was obtained from the Brazner (1997) study:

- Yellow Perch
 - Dominantly found in Green Bay Zone 2 (74 percent)
 - Dominantly found on wetland habitat (74 percent)
- Spottail Shiner
 - Dominantly found in Green Bay Zone 2
 - Dominantly found in beach habitat
- Alewife
 - Dominantly found in beach habitat
- Gizzard Shad
 - Dominantly found in Green Bay Zone 2
- Emerald Shiner
 - Dominantly found in Green Bay Zone 2
- Common Shiner
 - Dominantly found in wetland habitat
- Golden Shiner
 - Dominantly found Green Bay Zone 4
 - Dominantly found in undeveloped wetland habitat
- Common Carp
 - Dominantly found Green Bay Zone 2
 - Dominantly found in undeveloped wetland habitat
- Rainbow Smelt
 - Dominantly found Green Bay Zone 3
 - Dominantly found in beach habitat

Note: trends for brown trout (n = 2) and walleye (n = 9) were not evaluated because an insufficient number of individuals were collected.

2.2.4 Identification of Important Fish Species

The Lower Fox River and Green Bay contain a wide variety of fish species. Some of these are commercially and recreationally important (e.g., walleye, perch, bass, lake trout), while others serve as prey for other fish, birds, or mammals, and thus are important to the overall ecological health of the system. Important for the process of modeling is the identification of the valuable

fish species that are representative of the system, and should be included in the food web models as indicator species.

The Lower Fox River/Green Bay fishery is a vital resource that provides important ecological, economic, and cultural services. As part of the Great Lakes, Green Bay is part of the largest area of fresh surface water on earth and supports a diverse and significant fishery. Despite degradation brought on by various human impacts, the fishery remains a vital resource used by commercial, sport, and tribal anglers. Fish from the Lower Fox River and Green Bay, supported by the diverse habitats provided by the bay, comprise an important food source for piscivorous birds and mammals. The importance of the fishery resources of the bay is reflected in the extensive efforts expended by various government agencies to manage and protect the fishery resource of Green Bay (USFWS, 1999). For example, Yellow Perch and Walleye together accounted for approximately 84% of the total catch in Green Bay during 1990-1998 (WDNR Creel surveys, 1990-1998).

Commercial fishing and sport fishing are both important uses of the Lower Fox River/Green Bay fishery resources. Commercial fishing dominated historically and is still ongoing in Green Bay. However, recreational fishing currently contributes more to the economy than does commercial fishing. For example, in 1985, the landed value of commercial fishing in the Great Lakes was estimated to be \$41 million, compared to estimated spending by sport anglers of \$2 billion (Colborn et al, 1990). In 1963, the Wisconsin Department of Natural Resources introduced 9,000 rainbow trout into several Door County tributaries to manage the alewife population and to provide a sport fishery (Eggold, 1995). Because of the success of this initial stocking, the program was expanded to include other salmonids: brown trout, brook trout, lake trout, chinook salmon, and coho salmon (Hansen et al., 1990; Eggold, 1995). Since stocking began, the sport fishery has become an important industry (Colborn et al., 1990). The Wisconsin DNR estimates that anglers spent nearly 3 million hours fishing on Lake Michigan and Green Bay in 1998. A walleye fish stocking program below the DePere Dam from 1977 through 1984 attracted anglers to the region, and today this area is an established, regionally famous walleye fishing area (Wisconsin DNR, 1988).

Based upon the descriptions presented above, the important fish species that should be modeled within the Lower Fox River and Green Bay include the following:

Little Lake Butte des Morts to the DePere Dam

- Shiner Species (common, golden, emerald, spottail)
- Yellow Perch
- Common Carp
- Walleye

Green Bay Zones 1 and 2

- Shiner Species (common, golden, emerald, spottail)
- Gizzard Shad
- Rainbow Smelt
- Alewife
- Yellow Perch

- Common Carp
- Walleye

Green Bay Zones 3 and 4

- Rainbow Smelt
- Alewife
- Walleye
- Brown Trout

2.2.5 Life Histories of Fish Species in the Lower Fox River and Green Bay

The remainder of this section details receptor species descriptions, life history, and food preferences for the important receptor species identified in the Risk Assessment.

2.2.5.1 Forage Fish

Rainbow Smelt. Rainbow smelt (*Osmerus mordax*) are widespread and abundant non-indigenous pelagic planktivores in the Great Lakes (Jones et al., 1995). Smelt are common and important prey items for Green Bay, but are not found above the DePere dam in the upper Fox River. These fish average 15 to 20 centimeters in length, but despite their small size, they have comparatively large mouths. Rainbow smelt are olive colored on top, and silver with blue or pink iridescence on their sides. They also have a silver stripe on their sides.

Life Histories: While young-of-the-year fish are pelagic, as they age they move towards a bottom existence. They often school offshore, prefer cool clear water, and are most abundant in water depths of 18-26 m, although they can be found in water depths of 14-64 m (Becker, 1983). Optimum temperatures range from 6.1 to 13.3 °C and feeding is at a peak at 10 °C. Spawning occurs on sandy beaches near river mouths in the Great Lakes between late March and early May when the water temperatures reach 4 °C, and lasts approximately two weeks. Specifically, in Lake Michigan, spawning in Green Bay may be a week or two behind spawning in northern Lake Michigan because Green Bay remains covered with ice longer (Becker, 1983). Rainbow smelt reach sexual maturity in approximately 2 years (approximately 170 mm) and can live up to 8 years (Becker, 1983). Further discussion of habitat preferences is discussed in the next receptor description regarding alewife.

Dietary Preferences: Investigations have indicated that rainbow smelt dominantly feed on zooplankton as juveniles and adults (Mills et al., 1995; Urban and Brandt, 1993). However, in the inshore waters they may consume large number of fishes, including young-of-year alewife, young-of-year smelt, and sticklebacks, while other researchers have found them to feed on smelt, shiners, sculpin, yellow perch, burbot, and rock bass, as well as mayfly larvae and chironomid (Becker, 1983; Brandt and Madon, 1986; O'Gorman, 1974; Selgeby et al., 1978; Stedman and Argyle, 1985).

Smelt as Prey: Smelt have supplanted chubs as the principal food of Lake Superior's trout population and their importance on the food chain in Lake Michigan is similar. Brook trout, brown trout, lake trout, whitefish, herring, walleye, yellow perch, northern pike, and burbot all prey on smelt.

Alewife. Alewife (*Alosa pseudoharengus*) are non-indigenous small anadromous pelagic planktivores that prefer open water and sandy habitats. Individuals of these landlocked populations are generally half the size (averaging approximately 16 centimeters in length) of the marine alewife (approximately 36 centimeters in length) (Scott and Crossman, 1973a). Alewife are blue-green colored on top and silver on the sides, with thin dark stripes on their top and upper sides.

The alewife is abundant in Lake Michigan and Green Bay, and Becker (1983) indicated that alewives constituted 70 to 90 percent of the fish biomass in Lake Michigan. Alewives inhabit all levels of the lake and bay over all bottom types. However, they avoid cold water when possible, and during winter they migrate to the deepest and warmest water of the lake/bay (Becker, 1983). Alewives swim in dense schools and are the major prey of the trout, salmon, and other fish in the lake (UWSGI, 2000). In 1974, it was estimated that coho salmon consumed approximately 36 to 45 million kg (80 to 100 million pounds) of alewife, which was about 5 percent of the total alewife biomass (Becker, 1983). Also, more than 8.16 million kg (18 million pounds) have been caught and processed primarily as poultry feed since 1966 (Becker, 1983).

Life Histories: Alewife travel in dense schools, move towards nearshore waters in the spring (mid-March and April), and spawn during the early summer. Alewife may be found throughout Green Bay, but are limited from migrating beyond DePere on the River because of the presence of the dam. Spawning occurs from June to August and in Lake Michigan; peak spawning occurs in the first two weeks of July (Becker, 1983). Preferred temperatures for spawning have been estimated at 13 to 16 °C in Lake Ontario, although can also vary widely from 5 to 22 °C. After spawning, hatching takes place in about 6 days. These newly hatched young remain in the spawning grounds until in the late larval stage and then they move into deeper yet still protected waters. Larvae mature into juvenile fish at approximately 40 days after hatching (31 mm length) (Hewett and Stewart, 1989). By the fall, these juveniles are five to eight centimeters in length and begin to move offshore and to the bottom of the lake (Scott and Crossman, 1973a). These fish reach sexual maturity at two years and live for approximately five or six years.

Dietary Preferences: Alewife fry are both phototropic and pelagic, feeding on zooplankton. However, as they grow, the water depth in which the fish feed largely controls the diet. Both juvenile and adult alewife dominantly consume zooplankton, however, while young-of-the-year alewife only consume zooplankton (Urban and Brandt, 1993), adult alewife may also consume amphipods, chironomids, fish eggs and larvae (Hewett and Stewart, 1989). Zooplankton predominate for fish which feed nearshore, while amphipods are consumed in water depths over 9 meters (29.5 feet) deep (Becker, 1983). Additionally, gastropods have been found in alewives captured in the littoral zone, indicating the alewives feed on the bottom to some extent. Researchers have found that alewife consume *Daphnia* preferentially in the southern portion of Green Bay (Becker, 1983).

Urban and Brandt (1993) and Mills et al. (1995) have studied competition for zooplankton between alewife and rainbow smelt in Lake Ontario. Urban and Brandt (1993) found that young-of-the-year alewife and rainbow smelt use different areas of the same habitat, which decreases direct competition. Alewife tend to be in more shallow waters than the rainbow smelt and these preferences are dependent on water temperature more than prey availability or water depth.

Alewife prefer warm waters of 12 °C or more, while rainbow smelt prefer temperatures of less than 12 °C (Urban and Brandt, 1993). Mills et al. (1995) determined that copepods and small cladocerans were the main diet of both fish, but that overall, rainbow smelt consumed larger prey than alewife. Also, the size of zooplankton consumed by these fish was not significantly different between the young-of-the-year and adult fish.

Predation by alewives on native fish eggs and larvae may be contributing substantially to the decline of native fish species (Hewett and Stewart, 1989). In Lake Michigan yellow perch year-class strength has been inversely related to abundance of alewife (Brandt et al., 1987; Mason and Brandt, 1996) and alewife have also been implicated as a principle factor in the failure of lake trout populations (Holey et al., 1995; Jones et al., 1995). Becker (1983) indicated that prey selection may be dependent on depth; filamentous algae represent 50 percent of the stomach contents of fish taken in the shore zone of Green Bay and zooplankton represent the other 50 percent, while deep water amphipods dominate the diet when alewife feed in water depths of 9 to more than 30 m.

Alewife as Prey: Like smelt, alewife are an important component of the Green Bay food chain. Brook trout, brown trout, lake trout, whitefish, herring, walleye, yellow perch, northern pike, and burbot all prey on alewife.

Gizzard Shad. Gizzard shad (*Dorosoma cepedianum*) is an abundant omnivore found throughout the Lower Fox River and the southern half of Green Bay. Adults are generally 28 centimeters in length. Gizzard shad have a distinctive whip-like dorsal ray. They are silver-blue colored above, silver-white on the sides, and they have six to eight dark stripes on their top and upper sides.

Life Histories: As with alewife, low water temperatures in the winter are a limiting factor on population levels. General preferred temperatures range from 23 to 24 °C, and the upper lethal temperature is 36 °C. Populations can do well under conditions that would be adverse to other fish species: warm shallow waters with high turbidity. In fact, optimal conditions for adults are warm shallow areas (23 to 24 °C) that are highly turbid, with soft mud sediments and few predators; deep clear waters with steep shorelines are not preferred conditions (Becker, 1983; Williamson and Nelson, 1985). Although gizzard shad can tolerate high current waters, quite waters are preferred and densely vegetated areas are avoided. Generally these fish can be found in shallow offshore waters at or near the surface. Spawning begins when temperatures reach approximately 19 °C, although spawning temperatures can range from 10 to 21 °C, and in Green Bay spawning can occur in late April and continue until early August (Becker, 1983). Gizzard shad spawn over sandy or rock substrates under 2 to 4 feet of clear flowing water, and eggs adhere to submerged aquatic plants and stones (Williamson and Nelson, 1985). Gizzard shad reach sexual maturity in two years and live for approximately six years.

Dietary Preferences: Juveniles, up to about 30 mm, are visual particulate feeders that dominantly consume zooplankton and can influence zooplankton populations both directly, and indirectly through consuming phytoplankton (Roseman, 1996). Because of this control over zooplankton populations, gizzard shad have been shown to indirectly limit bluegill growth, another planktivore species. However, a study that investigated competition between young-of-the-year

gizzard shad and yellow perch found that competition did not limit growth for either species (Roseman, 1996). Past 30 mm in size, gizzard shad are pump and filter feeding omnivores, consuming zooplankton, phytoplankton and detritus. Generally this diet shift occurs around the time that zooplankton abundance is decreasing.

Some research has found that phytoplankton dominate in the gut when gizzard shad become omnivorous (Roseman, 1996), but other research indicates that phytoplankton consumption is small (< 5 percent by volume) and detritus becomes the major component in the diet (Mundahl and Wissing, 1988). Mundahl and Wissing (1988) found that gizzard shad are able to selectively consume detrital components from surface sediment that has the most nutritional value. Most feeding, however, does not occur at the sediment surface; rather, gizzard shad disturb the sediment and then consume detritus from mid water (Yako et al., 1996). Although this may be the major detrital feeding strategy, gizzard shad will also consume sand particles that are too heavy to be resuspended to mid water; sand consumption aids in digestion through grinding the food (Becker, 1983).

The stomach contents of gizzard shad were examined during the forage fish study by Muth and Busch (1989) in Lake Erie in 1975 (October) and 1976 (August and October). Gizzard shad were the only forage fish species that was found to eat algae extensively, up to about 25 percent of their diet. Ingestion of cladocera ranged from 4 to 49 percent, ingestion of copepods ranged from 3 to 20 percent, and diptera were not consumed. However, in a study of sediment contaminant ingestion by gizzard shad (Kolok et al., 1996), researchers noted that gizzard shad do feed on benthos and resuspend sediment. Williamson and Nelson (1985) acknowledged that gizzard shad feed through pumping and filtering; gizzard shad feeding in open waters have mostly phytoplankton in their stomachs, gizzard shad feeding in littoral vegetation have mostly zooplankton in their stomachs, and gizzard shad feeding in turbid waters have mostly mud in their stomachs. Given that gizzard shad may consume benthos, but likely prefer zooplankton, rates of prey items consumed were assumed to be 20 percent algae, 70 percent zooplankton, and 10 percent chironomids.

Gizzard shad as prey: Juvenile gizzard shad are important forage fish for predators such as walleye in Green Bay (Wolfert and Bur, 1992). However, because they are a fast growing fish, they are not optimal prey for long (Becker, 1983). Peak consumption of gizzard shad occurs when they are approximately 25 mm; by the fall, gizzard shad may be 90 mm and too big for some predators to consume (Michaletz, 1997). The fast growth of these fish, more than the population density, limits predator consumption, at least for small predators (Michaletz, 1997).

Shiner sp. Shiner species considered as receptors in the Lower Fox River and Green Bay include golden shiner (*Notemigonus crysoleucas*), emerald shiner (*Notropis atherinoides*), and common shiner (*Notropis cornutus*). All shiner species are relatively small forage fish that average 2 to 4 inches in length. Golden shiners are silver with a dusky stripe along their side and a small almost vertical mouth. Common shiners are olive on top with a dark strip running down the middle of their back, and one or two stripes along their upper sides. Emerald shiners are light olive on top, with a dusky stripe along their back, a silver stripe with emerald reflections along their side, and a large mouth.

Life Histories: Shiners are found throughout the Lower Fox River, and in the southern portions of Green Bay. Shiners generally inhabit shallow areas with limited current and rarely are found in riffles, but common shiners can tolerate some turbidity (Becker, 1983). Frequently these fish are found over similar substrates (sand, mud, gravel), but common and golden shiners are more dependent on vegetation than emerald shiners (Becker, 1983). Water temperatures can strongly influence the distribution of these fish; preferred temperature is 25 °C, but common and golden shiners have been shown to tolerate temperatures up to 34 °C (Becker, 1983). These open water fish rarely go below the thermocline (11 to 15 m). Shiners have a long spawning season, beginning in late May and continuing until August when water temperatures range from 17 to 27 °C (Becker, 1983). Golden shiners spawn on beds of submerged vegetation (Becker, 1983). Emerald shiners spawn on gravel, boulders, rubble or sand at depths of 2 to 6 m (Becker, 1983). Common shiners spawn on gravel beds in running waters and often eggs are spawned over the nests of other minnows (Becker, 1983). Shiners can spawn more than once and post-spawning mortality is significant, although fish can live for four years.

Hybrids between the common shiner and other species have been found in Wisconsin. For example, hybrids have been found between common shiner and emerald shiner, chub species, and dace species. This can occur because following spawning, common shiner eggs do not harden for approximately two minutes, allowing time for sperm from other species to fertilize the eggs.

Dietary Preferences: While zooplankton are the dominant prey of juvenile and adult golden and emerald shiners, common shiners ingest approximately equal amounts of animal and plant material and generally less zooplankton (Becker, 1983). Muth and Busch (1989) examined the dietary overlap of forage fish in Lake Erie in 1975 (October) and 1976 (August and October) by identifying the stomach contents of several fish species including emerald shiner and spottail shiner. These data indicated that emerald shiners were very dependent on cladocera, a zooplankton (80 percent of their diet by volume in October). Emerald shiners also consumed small quantities of diptera (fly larvae) and algae. The spottail shiner diet was found to be more diverse, where cladocera represented 2 to 19 percent of their dietary intake, copepods (zooplankton) and diptera each represented about 16 percent of their diet, and small amounts of algae were consumed. For our food web model we assumed that diptera and chironomids represented the same prey. Common shiners generally feed on equal portions of plant and animal material, with plant consumption increasing as turbidity increases (Trial et al., 1983). Other prey consumed by shiners include algae, terrestrial insects, small fish, fish eggs, aquatic insects, oligochaetes, amphipods, molluscs, plants, and detritus (Becker, 1983).

Shiners as prey: Due to their relatively small size, shiners are preyed upon by many game fish, including bass, crappies, walleye, northern pike, and muskellunge.

2.2.5.2 Predatory Fish

Yellow Perch. Yellow perch (*Perca flavescens*) are native to the Lower Fox River and Green Bay are one of the most important fish of Wisconsin and Michigan in terms of both the commercial and sports fishing industries. Yellow perch average 15 to 25 centimeters in length. They are green colored on top, whiteish on the underside, and they have distinct green-brown vertical bands extending down yellow sides.

Populations of yellow perch in Lake Michigan have widely fluctuated. As previously discussed, yellow perch year-class strength has been inversely related to abundance of alewife (Brandt et al., 1987; Mason and Brandt, 1996). Between 1889 and 1970, average catch rates were 2.4 million pounds per year from Green Bay, but because of the dramatic decline in perch since 1990 (a loss of 80 percent of the population), beginning in January 1997, Wisconsin banned commercial fishing and reduced daily recreational limits to five individuals per day.

Life Histories: The preferred habitat of yellow perch is shoreline areas with depths of less than 10 meters in clear lakes with temperatures of 18 to 21 °C, sand, gravel or muddy sediments, and modest to moderate amount of aquatic vegetation (Becker, 1983; Scott and Crossman, 1973b). A study examining the frequency of littoral fishes in a Wisconsin lake determined that yellow perch (young-of-the-year and adults) were highly associated with complex macrophyte beds (Weaver et al., 1997). Of the sites examined, the only locations where yellow perch were not caught were two sites having the lowest abundance of vegetation. Turbidity adversely affects growth of juveniles and temperatures of 32 °C can be lethal, but yellow perch are tolerant of low oxygen levels. In Lake Michigan, oxygen levels of 0.1 to 0.3 ppm killed numerous yellow perch, but many also survived (Becker, 1983).

Spawning generally occurs soon after ice leaves, beginning in April or early May in Lake Winnebago, and closer to mid-June in Lake Michigan (Becker, 1983; Wells and Jorgenson, 1983). Vegetated areas of shallow lakes and tributary rivers are often used as spawning sites (Scott and Crossman, 1973b). Nests are not built and eggs and young are not guarded. Egg extrusion can take minutes or several hours. Eggs are laid in gelatinous strands onto aquatic vegetation, submerged brush, or over sand, gravel, or rubble substrates in sheltered areas where waters are 0.6 to 3 m deep. Peak spawning occurs at temperatures of 7 to 19 °C (Becker, 1983). Egg incubation varies depending on location, but generally lasts 17 to 20 days. At hatching, larvae are about 5 mm long. They go up to the water surface and stay there for about 4 weeks, until they are about 25 mm long (Becker, 1983). After this, the fish move towards the bottom of lakes and by mid July these fish are approximately 102 mm (half of their first years growth).

In Lake Michigan, sexual maturity in perch has been found to be at 1 year for some males and 2 years for most males. All males greater than 5 inches were mature. In contrast, some females reached maturity in their second year but most matured by the third year and, a few not until their fourth year. Generally, females greater than 7 inches were mature (Wells and Jorgenson, 1983).

Dietary Preferences: Perch are a schooling species that feeds during the day and rests on the bottom at night. Prey consumed by yellow perch varies seasonally. Juveniles mostly consume zooplankton and chironomids. Feeding preferences of perch change with age and season; after the first year, yellow perch become increasingly piscivorous. As young fish, perch primarily feed on zooplankton and switch to a diet of benthic invertebrates, eggs, and young fish as they age (Scott and Crossman, 1973b). However, zooplankton are an important food source for all sizes of yellow perch (Becker, 1983). Although yellow perch will eat fish, chironomid larvae are the predominant food until 180 mm, and it is only after this size (around age 3 or 4) that fish become a major food item (Becker, 1983). In turn, perch are prey for several fish and bird species (Scott and Crossman, 1973b).

Yellow Perch as prey: Young yellow perch are preyed upon by all fish-eating species, including muskie, northern pike, burbot, smallmouth and largemouth bass, bowfins, bullheads, lampreys, and walleye (Becker, 1983). Walleye and yellow perch will prey on the other at different times in the life cycle: large walleye feed on yellow perch, while yellow perch feed on walleye fry. However, in Green Bay, yellow perch do not comprise a significant portion of the walleye diet.

Scott and Crossman (1973b), in their descriptions of yellow perch, stated that young perch primarily consume zooplankton and chironomids, and mature perch primarily consume immature insects, invertebrates, and fish. Krieger et al. (1983) reported that young yellow perch generally consume zooplankton, and that as they age begin to feed more on bottom dwelling species: amphipods, ostracods and chironomid larvae. In a more recent review of yellow perch (Carlander, 1997a) zooplankton were reported to significantly contribute to yearling and adult diets, while chironomids were major food items of adult perch. Based on these data, it was assumed that young of the year perch consume 90 percent zooplankton and 10 percent chironomids, and adult perch consume 50 percent zooplankton and 50 percent chironomids.

Carp. Carp (*Cyprinus carpio*) is an abundant bottom-dwelling species found throughout the Lower Fox River and southern Green Bay. Adult carp have been found to range in length from 41 to 58 centimeters, and weigh from 2.5 to 22 pounds (Weber and Otis, 1984). Carp have distinct two barbels on each side of the upper jaw. These fish are grey/grey-green colored on top, have a dark edge on the upper side, white to yellow on the underside.

Carp are tolerant to a wide range of conditions, but they prefer shallow lakes and streams, that have abundant aquatic vegetation and are warm (Becker, 1983). These fish are tolerant of turbidity low dissolved oxygen, pollution, and rapid temperature changes better than about any other fish in North America (Becker, 1983). Part of its ability to tolerate low oxygen is because it can use atmospheric oxygen. The preferred temperature for this fish in Wisconsin is 32 °C, but this is within the range of temperatures that have been found to be lethal (31 and 34 °C), and it is above a temperature at which spawning could occur (Becker, 1983).

Life Histories: Carp have the ability to range widely; some tagged fish have traveled 1090 km, and a carp tagged in Lake Winnebago was recaptured 148 km away (Becker, 1983). Most tagging studies of carp have found that they are generally recaptured within a few kilometers (Becker, 1983). Generally carp are wary and bolt for vegetation and cover or deeper water with little provocation. The exception to this behavior is spring when spawning occurs (Becker, 1983). Spawning occurs from April to August in Wisconsin and peaks in late May to early June when temperatures range from 18 to 28 °C (Becker, 1983; Scott and Crossman, 1973c). An investigation of spawning carp in Lake Winnebago and nearby lakes, determined that preferred spawning areas were shallow vegetated waters (0.5 to 4 feet deep) (Weber and Otis, 1984). These preferences have also been supported by other authors (Becker, 1983; Scott and Crossman, 1973c).

Incubation lasts for 3 to 16 days depending on the temperature (Becker, 1983). Four to five days after hatching, young move off vegetation and go to the bottom (Becker, 1983). Through their first summer, carp fry are strongly associated with vegetation as protective cover in 0.5 to 1 foot of water (Weber and Otis, 1984). Young carp leave this shallow weedy habitat when they are 76

to 102 mm and generally to large for predators to consume (Becker, 1983). After the first season of growth, carp are generally 13 to 19 centimeters long (Scott and Crossman, 1973c). Although young carp are food for both birds and other fish, when they reach 3 to 4 pounds, they are too large to be a prey item. Carp are generally mature at age two (males) or three (females) and usually live for 9 to 15 years (Becker, 1983).

Dietary Preferences: Carp are omnivorous, feeding equally on plant and animal matter (USFWS, 1982). Young-of-the-year (YOY) carp eat copepods, chironomids, and cladocerans. On a weight basis, chironomids are the dominant food source (Weber and Otis, 1984). The adult diet is generally half plant and half animal material that is taken from sediments and occasionally from the surface. Animal prey can include aquatic insects, crustaceans, annelids, molluscs, aquatic plants and algae. Fish or fish eggs may be taken but they are not a significant item in the carp diet (Becker, 1983). Plant material consumed can include green tree leaves, grasses, twigs, roots, and algae (Becker, 1983). Animal material is particularly important in the winter when plant material may not be consumed (Becker, 1983).

Scott and Crossman (1973c), in their descriptions of carp, stated that carp are omnivorous and consume both plant and animal material. Generally their feeding strategy is to take mouthfuls of bottom plant material, sediment material, and invertebrates, expel the material and consume the food items released from the sediment. Weber and Otis (1984) in their report on carp in Wisconsin, determined that chironomids were the bulk of the diet in young of the year carp and that young carp ate no plant material. Adults are opportunistic feeders, young carp initially feed on zooplankton and phytoplankton, with later feeding on worms and insect larvae (Weber and Otis, 1984).

Carp as prey: Carp, especially young carp, are preyed upon by many game fish, including bass, crappies, northern pike, bowfin, and walleye. Carp eggs are preyed upon by minnows, catfish, and sunfish (Becker, 1983).

Walleye. Walleye (*Stizostedion vitreum*) is a popular, year-round game and commercial fish found in Lake Michigan, generally in areas less than 7 m deep (Magnuson and Smith, 1987). These fish range in length from 33 to 64 centimeters and weigh from 0.45 to 2.3 kilograms. Adult walleye can also grow to weights that could exceed 2.3 kilograms. Walleye have huge mouths that extend past the eye and strong canine teeth (Becker, 1983). Walleye are yellow-olive/brown colored on top and brassy yellow-blue along sides. They have 5 to 12 dusky saddles that become less visible as they age (Becker, 1983).

Walleye are tolerant of a range of environmental conditions, particularly turbidity and low light, but they are not tolerant of low oxygen levels. Winterkills, because of low oxygen, have occurred in Wisconsin (Becker, 1983). Walleye prefer quite waters over sand, gravel, and mud substrates (Becker, 1983). They rest in deep dark waters during the day and migrate to rocky shoals and weed beds to feed at night, but they may be active during the day if it is cloudy or the waters are turbid (Becker, 1983). YOY fish can be found near the sediments in 6 to 10 meters of water (Scott and Crossman, 1973d), but can be caught in surface waters up to lengths of approximately 35 mm (WDNR, 1970). Larger fish are generally in depths of 14 meters or less

and form loose schools (Scott and Crossman, 1973d). Schooling is common during feeding and spawning.

Life Histories: Summer territories and spawning grounds are distinct areas, and walleye may have a homing instinct for spawning grounds. The range of summer area is generally limited to 3 to 8 km, but the recorded range has varied from 0.8 to 110 km. A study of walleye in Lake Poygan found that walleye traveled an average distance 47 km (Becker, 1983).

Walleye spawn soon after ice melts and temperatures reach 3 to 7 °C and spawning peaks when temperatures are 6 to 10 °C (Becker, 1983). In Lake Winnebago, the timing of spawning has been recorded as a 2- to 3-week period between the first week in April and the first week in May (WDNR, 1970). Walleye from Green Bay move upstream into the Fox River to spawn, however, their movement is restricted by the DePere dam (Magnuson and Smith, 1987). Walleye do not build nests and after releasing eggs, they offer no parental care. Spawning occurs at night generally on gravel bottoms, but they can spawn on vegetation. In Lake Winnebago flooded marsh areas are preferred spawning grounds (Becker, 1983). Continuous flowing water over the eggs is important for hatching success. The time for eggs to hatch is dependent on the water temperature: at 14 °C, eggs hatch in about 7 days and when water temperatures are 4 °C eggs hatch in about 26 days (Becker, 1983). Fry move off wetlands a day or two after hatching and obtain an open water existence. They stay in open water until they are about 30 mm and then return to shore around June (Becker, 1983). By the end of July, walleye in Lake Winnebago are about 75 mm or larger. At this size, walleye shift their diet from zooplankton only to also include fish and invertebrates, and by fall they are generally 130 mm (Becker, 1983). Male walleye reach maturity at 2 to 4 years old and females reach maturity at 3 to 6 years old (Scott and Crossman, 1973d). Few walleye live beyond six years old (Becker, 1983).

Dietary Preferences: Walleye diet is seasonally dependent. Feeding is infrequent when water temperatures are below 15°C, and feeding is generally greatest in the summer and early fall when forage fish are abundant. Young-of-the-year walleye are believed to eat mainly phytoplankton, including diatoms and blue-green algae. Fry and young-of-the-year walleye up to 30 mm feed primarily on plankton crustaceans and insect larvae (Becker, 1983). At approximately 30 mm in length, young walleye begin to feed on fish, including alewife and yellow perch. For older walleye, fish dominate the diet except during times when prey fish are less abundant, in which case; walleye will feed on benthic invertebrates. For both young of the year walleye and older walleye, prey is selected that is less than 90 mm total length (Wolfert and Bur 1992; Knight et al., 1984).

Wolfert and Bur (1992) examined the stomach contents of both young of the year and older walleye in Lake Erie. In terms of identifiable food items, young of the year walleye had mostly eaten white perch, yellow perch, gizzard shad, rainbow smelt, and emerald shiner, and had consumed zooplankton and chironomids to a lesser extent. In older walleye, stomach contents contained rainbow smelt, white perch, chironomids, gizzard shad, and freshwater drum.

Walleye diets were investigated in spring and fall in three areas of the Lower Fox River and southern Green Bay system: just below the DePere dam, at the mouth of the Lower Fox River

(fall only), and in Green Bay Zone 3 (Magnuson and Smith, 1987). Magnuson and Smith reported on the stomach contents of walleye from lower half of Green Bay. Results indicated that of the forage fish consumed, alewife represented 50 percent by weight, and rainbow smelt and gizzard shad were each approximately 25 percent by weight. Invertebrates were only observed in stomachs of smaller walleye from near the mouth of the Lower Fox River and it was proposed that invertebrates were selected as prey only when forage fish were not available. The reviews of walleye conducted by Carlander (1997b) and McMahon et al. (1984), also indicated that yearling and older walleye mostly consumed young of the year fish, and to a lesser extent, chironomids.

Brown Trout. Brown trout (*Salmo trutta*) is a popular, seasonally caught game fish Green Bay. These fish range in length from 41 to 61 centimeters and weigh from 0.9 to 3.6 kilograms. These fish are light brown to brown-black in color with red and black spots, but on the lower sides and stomach, they are silverish. Brown trout have large jaws.

As compared to other species of trout, brown trout grow faster, live longer, and better tolerate degraded habitats, warm temperatures (up to 29 °C), and turbidity (Becker, 1983). They are fairly common in cold waters of Wisconsin and self-sustaining populations in Lake Michigan are enhanced with stocking. In Green Bay, this species is generally limited to the northern two-thirds of the Bay, which contain deeper and colder waters. Preferred temperatures are 10 to 18 °C (Becker, 1983).

Life Histories: Brown trout are most often found along the shore in waters no deeper than 15 meters (Becker, 1983) and they have been known to inhabit waters along the west shore of Green Bay from the towns of Oconto and Marinette (Magnuson and Smith, 1987). Wild brown trout fingerlings that were tagged have been found to travel an average of 16 km in one year. Hatchery reared trout released in Wisconsin waters generally remained within 24 km of the release point, but some tagged fish after one year were found to range up to 323 km (Becker, 1983).

Spawn occurs when waters are close to 8 °C, in autumn and early winter (October to December). Spawning areas are shallow waters with gravel bottom substrate, generally stream headwaters rather than rocky shores, but spawning does occur in lakes along rocky reefs. Females build nests and males defend them. Unlike salmon, these fish do not die after they spawn and most individuals spawn more than once. During spawning, these fish may school, but when not spawning, crowding is not tolerated (Becker, 1983). Generally, brown trout are sexually mature at two years old and live for approximately seven years.

Dietary Preferences: Brown trout generally tend to be nocturnal feeders, and food items can include aquatic and terrestrial insects, crustaceans, molluscs, frogs, shrimp, salamanders, and other fish. Zooplankton are an important food source for small brown trout (Becker, 1983). Up to about 229 mm they are insect feeders and past this length they dominantly consume (70 percent of the diet) fish such as young trout, sculpins, minnows, darters, and lampreys (Becker, 1983). Magnuson and Smith (1987) found that brown trout collected in the spring from Green Bay Zone 3 dominantly consumed alewife (73 percent of the diet); rainbow smelt were the other 27 percent of the identified forage fish consumed. Half of the brown trout collected in the fall in

this region of the Bay had empty stomachs and, therefore, prey consumption was not evaluated (Magnuson and Smith, 1987). It is suspected that over the summer, brown trout, like walleye, increase their consumption of rainbow smelt (Magnuson and Smith, 1987).

3. Food Web Structure

Based upon the life history, and diets described above, conceptual food web models were developed for the Fox River and Green Bay. Figure 1 presents the recommended food web to model fish tissue accumulation of PCBs within this section of the river. This food web includes both benthic and pelagic routes of uptake and transfer of PCBs. Figure 1 also reflects the food web above DePere includes a phytoplankton component which form a significant portion of the diet for gizzard shad, and indicates that species such as alewife and rainbow smelt are not found above the DePere dam.

Figure 2 reflects the food web to be used for the area between the DePere dam (the southern boundary of Zone 1) and the northern boundary of Zone 2 in Green Bay. Figure 2 shows that the food web for Zones 1 and 2 includes phytoplankton and zooplankton are prey components for both young of the year carp and walleye. Benthic organisms are included as a small, but seasonally important part of the diet for all the fish species represented in the food web. Dietary assignments are based principally on the stomach content analysis for walleye in lower Green Bay (Magnuson and Smith, 1987), as well as field experience and knowledge of WDNR fisheries biologists.

Figure 3 reflects the food web to be used to represent Zone 3 and 4. The food web used in the Green Bay Food Web Model (GBFOOD) (Connolly et al 1994) represents predator/prey relationships in upper Green Bay.

For the forage fish, the food web structure used in Connolly et al. (1992) was updated to include information published in more recent literature. Analysis of the stomach content data presented by Magnuson and Smith (1987) served as the basis for the food web structures for walleye and brown trout. These walleye and brown trout food webs were compared to those developed by Connolly et al. (1992) and refined, if necessary, to maintain consistency between analyses. A discussion of the food web for the each species is presented below.

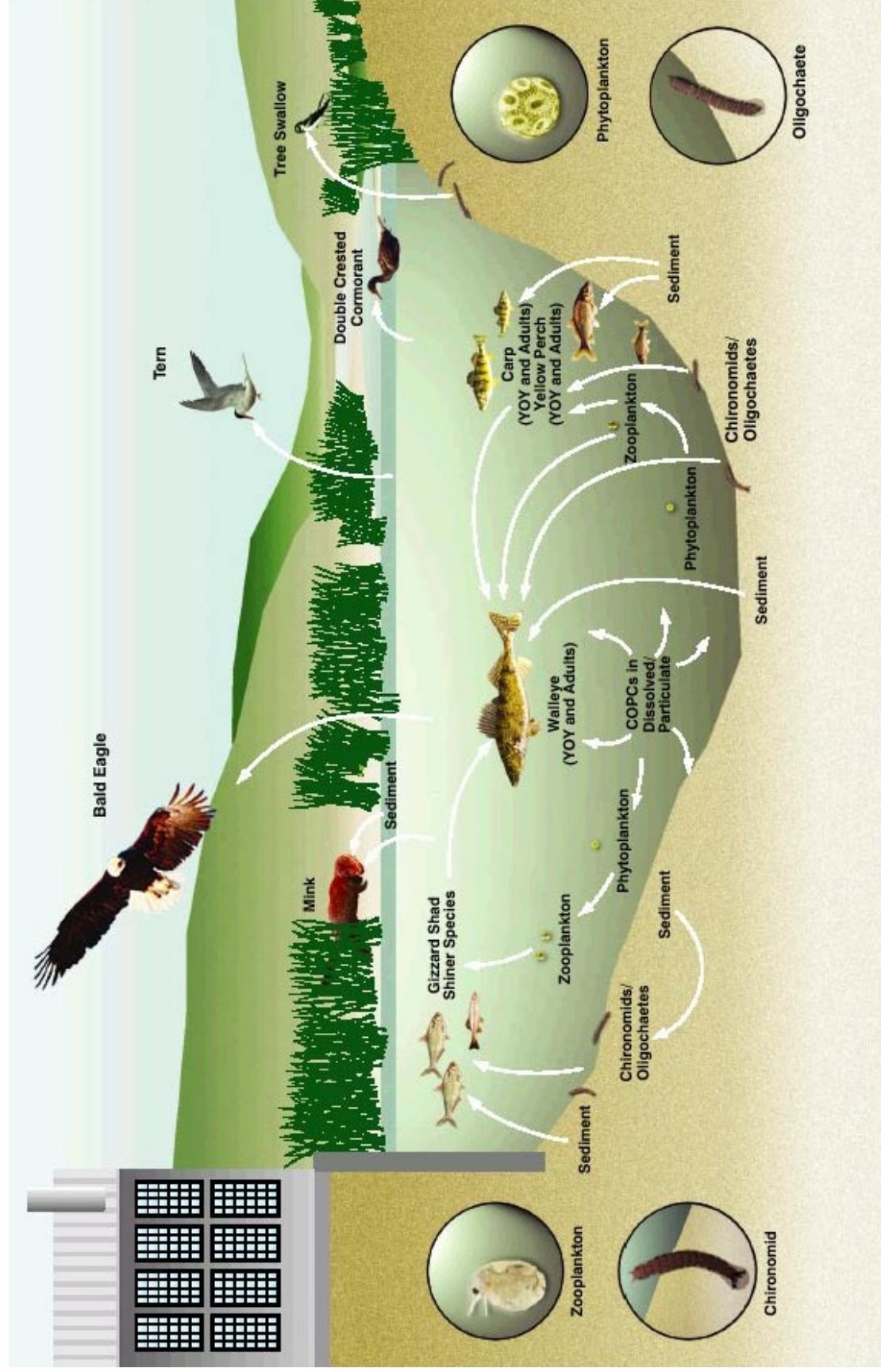


Figure 1. Food Web Structure: Little Lake Butte des Morts to the DePere dam.

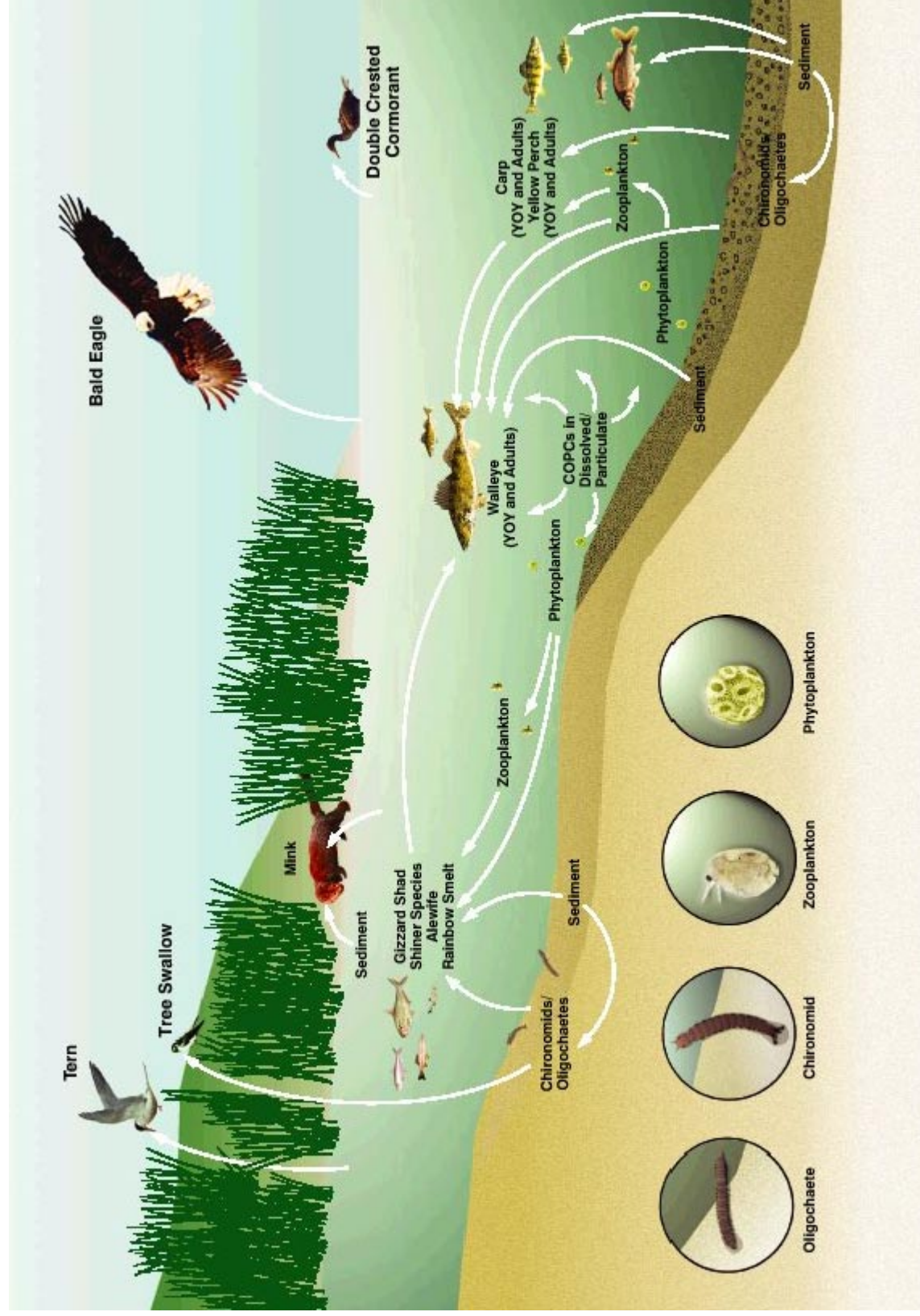


Figure 2. Food Web Structure: Green Bay - Zones 1 and 2.

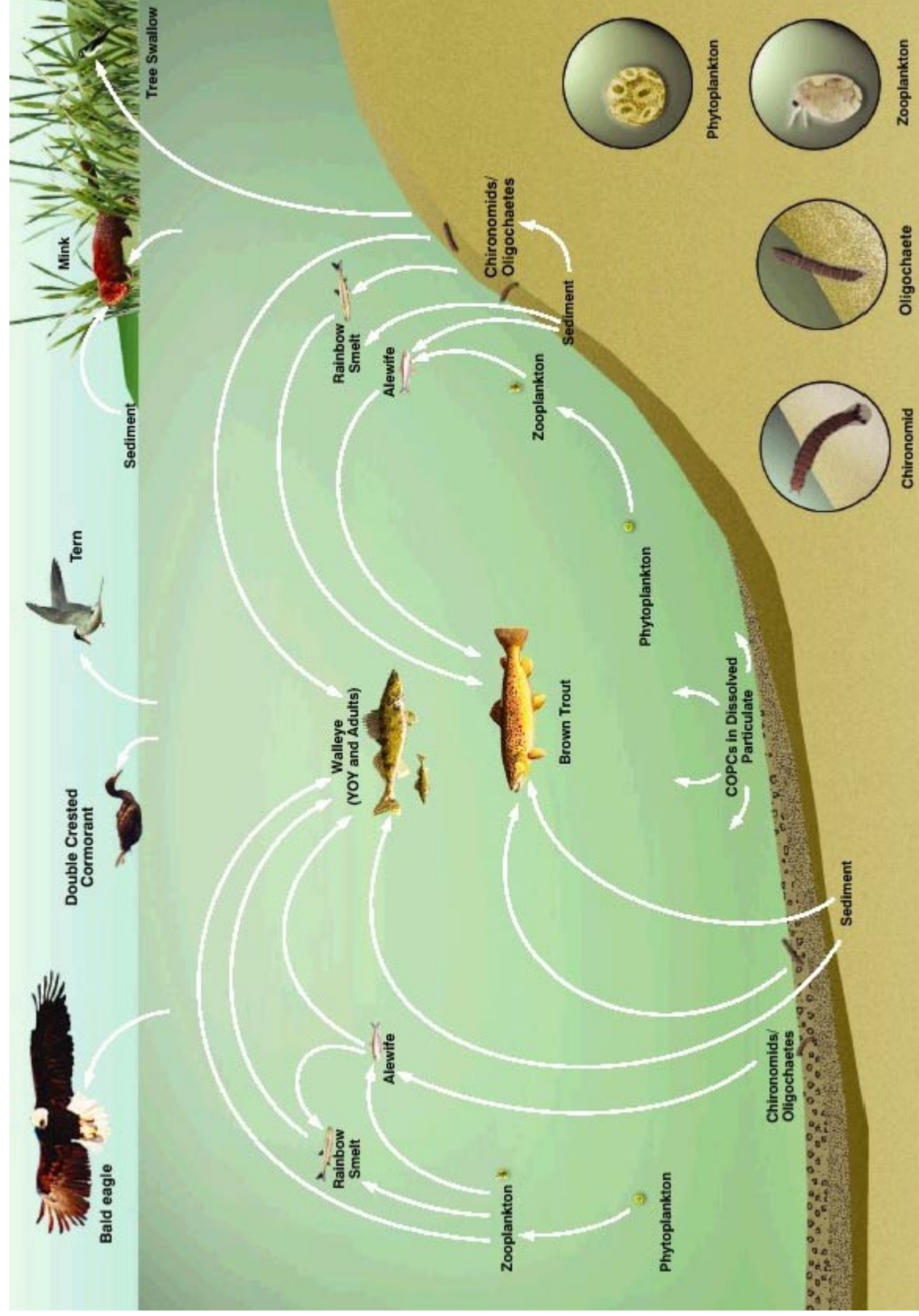


Figure 3. Food Web Structure: Green Bay - Zones 3 and 4.

4. Fish Migration Patterns in Green Bay Zones 1 and 2

Experience and data of WDNR fisheries biologists suggest that fish in Green Bay Zones 1 and 2 constitute a single fish population which is predominately exposed to PCBs in Zones 1 and 2 on a continuous basis. This is based upon tagging studies conducted by Department that have shown that both predator and prey fish migrate in and out of the River, but in general those same species are resident within Zones 1 and 2. While some data may suggest that species reside principally in the River during winter and migrate into the Bay during summer, those data were insufficient to ascribe time-weighted proportions to residence times in either zone.

An extensive database of fish species collected in assessment surveys downstream of the dam at DePere, and portions of Green Bay (1981 to present) has been developed. These assessments occurred throughout Green Bay and include Sturgeon Bay, southern Green Bay, tributary streams to Green Bay, and the Lower Fox River downstream of the DePere dam to the river mouth (WDNR Creel surveys, 1990-1998). These data include records of all individual specimens tagged during the course of surveys. Through 1998 approximately 120,000 individual fish had been tagged. While the majority of species tagged are walleye, at least forty other species were tagged, and include both game and non-game species.

On the basis of tag returns from these fish, which in early 1999 exceeded 12,500 recaptures, it is evident that significant movement between the Lower Fox River and Green Bay occurs¹. Fish tagged in the Lower Fox River have been recaptured in the Menominee River, the Oconto River, Fish Creek and Sturgeon Bay, as well as in southern Green Bay (Zone 2). Similarly, fish tagged in Zone 2 have been recaptured in areas north of Zone 2 as well as in the Lower Fox River (Zone 1). Similar trends were observed for fish tagged in Zone 3 but to a lesser degree. However, the data does not allow an exact quantification of the movements of fish in this area. It is important to note that the recovery (survey) effort between zones is unequal in terms of the effort that WDNR Fisheries and Habitat staff expend in surveys among the areas as well as in terms of angler effort (fishing pressure) which also provides tag return data.

Further evidence of movement between zones is suggested by seasonal changes in relative abundance of species in data collected from fyke nets and electrofishing in the Lower Fox River (WDNR Creel surveys, 1990-1998). As an example, walleye increase in abundance from mid-summer levels too late fall and continue to increase during the spring prior to spawning. After spawning the relative abundance decreases suggesting that many walleye leave the river and return to the Green Bay, but a smaller yet still significant number of walleye remain in the river throughout the summer. It can not be determined from the data if an exchange of the previous summer's Lower Fox River walleye to Green Bay has occurred in this mass movement of individual fish and conversely if some walleye entering from Green Bay remain in the Lower Fox River.

¹ These data are based upon both fyke net capture, as well as boom electro-shock fish counts made in Zones 1 and 2. Because of the limitations of the sampling equipment, the discussion regarding migration between the two zones is restricted to mature, adult fish. For example, walleye in the samples were at a minimum older than two years, but generally are third year mature fish. In the case of yellow perch, there were at least two years old. For younger fish, generally the data presented by Brazner is more pertinent.

Seasonal changes in relative abundance of other species found in the Lower Fox River suggest a similar interpretation of their behavior. Yellow perch show increases in numbers of fish within the River during the Spring spawning period only, with a smaller number of fish present in the River throughout the rest of the year. Both northern pike and white sucker are more abundant in the spring in Zone 1, the Lower Fox River. But, as with walleye, they can be found in the Lower Fox River at all times of the year but in lower numbers. Alewife are generally not found in Zone 1, except for a period of four to six weeks between May to early June when they will aggregate in mass in the River.

Tag return data suggest that fish will move considerable distances within Green Bay. An area of continued uncertainty is whether fish return annually at approximately the same time each year or whether they stay in the river while other fish leave. Department fisheries biologists interpret those data to indicate that some fish primarily remain in one zone or another, but that many migrate between zones on a relatively frequent basis. For example, movement of walleye between Sturgeon Bay, Marinette, and the Lower Fox River and/or Southern Green Bay is very limited. Walleye tend spend a majority of their time to their respective areas while movement between areas occurs on a less frequent basis.

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